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Title:

Bias Circuit Linearization and Dynamic Power Control

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Related Applications

[0001] The present application is related to and claims priority benefit of the filing date of a United States provisional patent application titled: HBT BIAS CIRCUIT LINEARIZATION AND DYNAMIC POWER CONTROL; Serial No. 60/410,842, filed September 13, 2002, which is hereby incorporated by reference into the present application.

Background

[0002] The present invention is generally directed to the design and implementation of complex circuits to reduce distortion and linearize the output corresponding to radio frequency (RF) and microwave frequency ranges. An embodiment of the present integrated ciruitry (IC) is configured to use a combination of Heterojunction Bipolar transistors (HBT) and resonant circuits to effectively provide lineariztion and dynamic power control for RF and microwave signals.

[0003] Today, one problem with operating a power amplifier at low distortion levels is that the efficiency of the amplifier circuit is greatly reduced because it is not amplifying at its highest capability. Therefore, a circuit according to the present system can preferably utilize a bias circuit to adjust the bias characteristics and subsequent power amplification corresponding to changing circuit conditions.

[0004] Specifically, the circuit may preferably utilize a leakage current of the RF input to determine the state of amplification and accordingly adjust the bias. By adjusting the bias conditions and power amplification characteristics to the existing conditions, power amplification efficiency is greatly improved.

[0005] Demands on the linearity and efficiency of power amplifiers are common in radio frequency and microwave communication systems. Conventionally, power amplifiers normally operate at maximum efficiency at or near saturation. However, in order to accommodate the linearity of today's devices with communication signals having varying amplitudes (e.g. cellular telephones), systems utilizing conventional power amplifiers normally operate at less than peak efficiency for a substantial portion of the time.

[0006] Of course, in today's market, wireless communications devices, such as cellular telephones, must consistently provide clear and undistorted transmissions. As well, the batteries in the devices must be small in physical size while maintaining a long operating life.

[0007] In order to meet these consumer requirements, wireless telephone designers and engineers have moved away from using traditional silicon-based bipolar transistors in power amplifiers and toward using more exotic transistors, such as heterojunction bipolar transistors ("HBTs") made of aluminum-gallium-arsenide/gallium-arsenide ("AlGaAs/GaAs") and indium-gallium-phosphide/gallium-arsenide ("InGaP/GaAs"). Such HBTs provide outstanding power efficiency and high linearity, thus enabling cellular phones to achieve longer battery life and better signal characteristics for voice and data.

[0008] Additionally, the trend in data networks is to provide higher data rates with complex modulation schemes. Complex modulation schemes require the design and implementation of linear systems in order for data transmission to be successful. In most cases, linear system design places significant constraints on individual circuits within the system.

[0009] Quite often the modulated signals applied to the system have very high peak-to-average-power-ratio (PAPR) which requires the individual circuits in the system to be designed so that they can withstand a large range of power levels. Essentially, the individual circuits must be designed with a large dynamic range, which makes the circuits inefficient and expensive.

[0010] Ultimately, circuit linearization techniques provide solutions to problems associated with signals requiring large dynamic ranges. Techniques that implement feedback, predistortion, feedforward, and other signal processing concepts are not feasible for use in RFIC designs. The technique used in the present embodiments allows for linearization and dynamic power control to be implemented in RFICs by manipulating aspects of the bias circuitry.

[0011] The present circuitry provides a linear amplifier configured with a bias circuit which is capable of realizing a high-efficiency operation during high output, while maintaining a linear operation.

[0012] Additional embodiments, advantages and novel features of the invention will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art upon examination of the following or may be learned by practice of the invention.

Summary of the Invention

[0013] In accordance with one embodiment, a transistor bias circuit is provided that is capable of biasing an amplifier transistor having a control terminal, a current-sink terminal, and a current-source terminal.

[0014] The bias circuit comprises a bias transistor having a control terminal, a current-sink terminal, and a current-source terminal. A first DC input port is connected to the current sink terminal of the bias transistor is provided. A first resonator element is connected between the current-sink terminal of the bias transistor and ground. A second DC input port is connected to the control terminal of the bias transistor. A diode element is connected between the control terminal of the bias transistor and ground. A second resonator element is connected between the control terminal of the bias transistor and ground. Finally, a resistive element is provided and connected between the current source terminal of the bias transistor and the control terminal of the amplifier transistor.

[0015] The bias transistor according to one embodiment may be one of a BJT, an HBT and a FET. Likewise, the amplifier transistor according to one embodiment may be one of a BJT, an HBT and a FET.

[0016] In another embodiment, the first, second and third resonators may individually be RLC circuits. Additionally, the diode element may include a plurality of diodes. Also, the resistive element may be a resistor, an RLC circuit or a combination of both.

Brief Description Of The Drawings

[0017] It will be appreciated that the illustrated elements in the figures represent one example of the elements. One of ordinary skill in the art will appreciate that one element may be designed as multiple elements or that multiple elements may be designed as one element. An element shown as an internal component of another element may be implemented as an external component and vice versa.

[0018] Figure 1 is a circuit diagram of an embodiment of an RF transistor amplifier with an impedance controlled bias circuit;

[0019] Figure 2 is a circuit diagram of an embodiment of an RF transistor amplifier with an alternate impedance controlled bias circuit; and

[0020] Figure 3 illustrates one embodiment of a plot of RF transistor base current supplied by the bias circuit utilizing different resonator impedances.

Detailed Description Of Illustrated Embodiments

[0021] Among those benefits and improvements that have been disclosed, other objects and advantages of this invention will become apparent from the following description taken in conjunction with the accompanying drawings. The drawings constitute a part of this specification and include exemplary embodiments of the present invention and illustrate various objects and features thereof.

[0022] Throughout this description, the embodiments and examples shown should be considered as exemplars, rather than limitations, of the present circuit. Of course, these embodiments and examples are not intended to be limiting and other embodiments may be implemented.

[0023] An HBT, like a bipolar junction transistor ("BJT"), requires a direct-current current ("DC") bias signal comprising both a voltage and a current to be applied to its input terminal to establish its operating point. The operating point of a transistor may be defined as the point on the transistor's characteristic curves at which the transistor will operate in the absence of an input signal.

[0024] Because changes in the DC bias signal affect the operating point of an HBT thus affecting the linearity of the amplifier, the DC bias signal must be very stable. Additionally, the DC bias signal must be unaffected by variations in temperature or in the power supply voltage. Such a DC bias signal is normally generated by a "bias circuit."

[0025] Briefly describing one embodiment of the present system, it provides for a circuit including a main amplifier circuit and a bias circuit. Generally, the circuit is configured to utilize an RF drive level to alter the electrical characteristics of a bias circuit surrounding a main RF amplifier in order to provide Intermodulation (IM) cancellation and dynamic power control.

[0026] Figure 1 illustrates an embodiment of the present system under normal operation. Generally, the embodiment includes a bias circuit **100** and a main amplifier circuit **105**. Each of these components will be discussed in greater detail below.

[0027] As shown in the embodiment of Figure 1, the bias circuit **100** comprises a first DC voltage input **110** connected to the collector terminal of a bias transistor **115**. A first RLC circuit or resonator **120** is connected to the collector terminal of the bias transistor **115** on one end and to ground on the opposite end as shown.

[0028] A second DC voltage input **125** may be connected to the base terminal of the bias transistor **115**. As well, a second RLC circuit or resonator **130** is connected to

the base terminal of the bias transistor **115** on one end and to ground on the opposite end as shown. Additionally, two diodes **135**, **140** in series are connected to the base terminal of the bias transistor **115** on one end and to ground on the other end.

[0029] A resistor **145** and third RLC circuit or resonator **150** are connected in parallel to the emitter terminal of the bias transistor **115**. The opposite end of the parallel configuration is connected to the primary amplifier circuit **105** at terminal 1.

[0030] Continued reference to Figure 1 illustrates the primary amplifier circuit **105** comprising an RF input **155** connected to the base terminal of an RF transistor **160** separated by a serially connected AC coupling capacitor **165** and resistor **170**. The emitter terminal of RF transistor **160** is connected to ground. A third DC input voltage **175** may be connected to one end of choke **180**. The opposite end of choke **180** is connected to the collector terminal of the RF transistor **160**. Finally, an RF output **185** is connected to the collector of transistor **160**.

[0031] The operation of the circuit under normal conditions will be better understood with reference to Figure 1. As shown, Figure 1 illustrates one embodiment of the bias circuit **100** in accordance with normal operation. In this embodiment, a bias transistor **115** and various resonator circuits **120, 130, 150** are configured to provide controlled impedances to the system thus optimizing the biasing and operation of the RF transistor **160**.

[0032] Under normal conditions, the RF input **155** signal flows through the AC coupling capacitor **165** and resistor, R2 **170** and into the base of the RF transistor **160**. Also under normal operation, DC voltage **175** is applied to the collector of the RF transistor **160**.

[0033] Upon regulating the DC input voltages **110, 125**, the bias circuit **100** provides a bias current to the RF transistor **160** through R1 **145** and R2 **170** in order to bias the RF transistor **160**. In this case, the resistor, R2 **170**, functions as both an impedance matching element as well as a current setting ballast resistor. The RF

transistor **160** subsequently amplifies the RF input signal **155** increasing the output **185**.

[0034] Illustrated in Figure 2 is an alternate embodiment of the present circuitry. The circuitry in Figure 2 includes a bias circuit **200** having various resistors, inductors and capacitors to provide specific impedances at desired points to allow for optimized RF signal leakage into the bias circuit **200**. As a result of the optimized RF signal leakage, the bias circuit can be configured to linearize the RF output signal as well as provide bias point shifts. In doing so, the bias circuit is configured to allow for a wide dynamic range of output powers which are extremely linear while maintaining high efficiency.

[0035] Continued reference to Figure 2 illustrates that the alternative embodiment generally provides a circuit design configured to utilize the RF input **155** and corresponding leakage to affect the performance of the bias circuitry **200.** In other words, the basic operation of this alternate embodiment utilizes the an RF input signal leakage into the bias circuit **100** to provide a means to both linearize the RF output **185** and cause the bias current into the RF transistor **160** to increase.

[0036] In operation, as under normal conditions, the RF input signal **155** flows through the AC Coupling Capacitor **165** and R2 **170** and into the base of the RF transistor **160**.

[0037] Additionally, an RF input signal leakage flows into the bias circuit **200** at terminal 1. An artisan will appreciate that the amount of RF input signal leakage entering the bias circuit **200** at terminal 1 may be controlled by a combination of the impedance of both the resistor R1 **245** as well as the Resonator 2 **250**.

[0038] Next, the RF input signal leakage flows through both a bias transistor **215** base to emitter diode junction as well as a bias transistor base to collector diode junction. As shown in Figure 2, the alternate connection of bias transistor **215** permits the RF input signal leakage flow into the collector terminal of bias transistor **215** from the parallel impedance configuration or R1 **245** and Resonator 2 **250**.

[0039] The combination of Resonator 1 **230** and Resonator 3 **220** provide controlled impedances that prompt the RF input leakage signal to both cancel Intermodulation (IM) distortion products and shift the bias point by utilizing the bias transistor's diode junctions.

[0040] The IM distortion is canceled by utilizing the bias transistor's diode characteristics in conjunction with the resonant circuits **220, 230** to provide a specific phase and amplitude of the IM products to the base of the RF transistor **160**. The summation of the original RF input signal **155** and the RF input signal altered by the bias circuit **200** produces a lower IM distortion input signal.

[0041] Next, this lower IM distortion combined input signal is amplified by the RF transistor **160**. It will be appreciated that utilizing the diode characteristics of the bias transistor **220** in conjunction with the resonant circuits **220, 230** to shift the bias transistor's DC operating point may also provide dynamic power control of the RF output **185**.

[0042] Reference to Figure 3 illustrates that the bias transistor's DC operating point shifts as the RF input signal level increases and thus forces more DC current into the RF transistor **160**. Essentially, both the bias circuit shift and the IM cancellation allow for better efficiency at both low and high RF output power levels. As described by the embodiments, the present invention provides a means to incorporate linearization and dynamic power control on an RFIC with smaller device sizes.

[0043] It will be appreciated that although the embodiment described herein discloses a bias circuit utilizing an HBT. Other types of transistors known in the art may be used without departing from the scope of the embodiments. For instance, alternative embodiments may use npn-type or pnp-type BJTs, other varieties of HBTs, or field-effect transistors ("FETs").

[0044] In summary, it will be appreciated that the present embodiment utilizes a multitude of linearization techniques into the circuitry to manipulate the HBT bias

circuit. Furthermore, it will be appreciated that these manipulation techniques may permit the present technology to be implemented in RFIC processes.

[0045] Of course, it will be understood that the present system may be used in applications where the characteristics of the power amplifier circuit can be modified to compensate for changing conditions. One example of an implementation where compensation for changing conditions obtains benefits is a power amplifier circuit in a cellular telephone.

[0046] One skilled in the art will recognize that the power amplification requirements of a cellular telephone change in accordance with the conditions under which the telephone is operating. For example, when the telephone operates in a region that is saturated with cellular traffic, high-accuracy cellular signals are required to limit interference from other cellular signals. In a less saturated region, the cellular signals can be relatively less accurate because there are fewer competing cellular signals to avoid.

[0047] In alternative embodiments, the power amplifier and bias circuits according to the invention may be implemented in circuits for use in a multitude of wireless communications networks. These networks, for example, may include wireless modems, wireless LAN, wireless Personal Area Network (PAN), digital communication systems, and the like.

[0048] It will further be understood that the wireless communications network may also be adapted to work with a low-powered radio system which allows products containing similar technology to be interconnected via wireless communication. This low-powered radio technology may preferably provide connection to a wide range of computing and telecommunication devices via wireless connections as is known in the art.

[0049] While the present invention has been illustrated by the description of embodiments thereof, and while the embodiments have been described in considerable detail, it is not the intention of the applicants to restrict or in any way limit the scope of

the appended claims to such detail. It is obvious that equivalent alterations and modifications will become apparent to others skilled in the art upon the reading and understanding of this specification. The present invention includes all such equivalent alterations and modifications.

[0050] Therefore, the invention, in its broader aspects, is not limited to the specific details, the representative apparatus, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of the applicant's general inventive concept.